Agent Based Models for Quantifying Food Security: Insights for Policy and Decision Making

Rosemarie Santa González[1], Alan Zhong[2],
Charlie Haight[2], Nolan Fiss[2], Carlos Guzman[3], Alfonso Morales[2]

Georgia Institute of Technology[1], University of Wisconsin Madison[2], Ohio State University[3]

AI Institute for Advances in Optimization

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Motivation

The United Nations' Sustainable Development Goal (SDG) 2, "Zero Hunger," aims to end hunger and promote equitable food access globally, yet food insecurity remains a pressing issue even in developed countries like the United States. **Vulnerable populations often face significant barriers to obtaining nutritious food** due to structural disparities in distribution infrastructure, which create food deserts and limit food quality options. This study presents the **Food Access Strategy Simulator (FASS)**, an agent-based model (ABM) developed to help policymakers understand and address food access gaps. By simulating individual and community behaviors in relation to food distribution points, such as supermarkets and food pantries, FASS offers data-driven insights to enhance equity in food accessibility and guide informed decision-making.

Methodology

FASS leverages Agent-Based Modeling (ABM), a simulation technique well-suited for capturing the complex dynamics of food distribution and access. ABM enables individual entities, or agents, representing households, to interact within a defined environment based on specific behaviors, reflecting real-world conditions at a granular level. Built as a standalone Python library, FASS offers flexibility by integrating various agent behaviors and environmental factors. Household agents are characterized by detailed attributes—such as income, household size, and vehicle access—that shape food access decisions. This approach provides a realistic model of food accessibility that can be adapted to different scenarios and demographics, making it a valuable tool for policymakers.

Agents

In FASS, each household agent is assigned specific characteristics including: ***income level, household size, employment status, and transportation availability.***

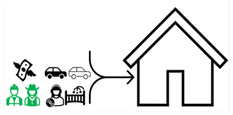

Figure 1. Household: Agent in FASS

These characteristics influence the agents access to food and allow the model to capture unique household circumstances often missed in aggregate analyses, providing a clearer picture of access disparities.

Figure 2. Interface: Agents in FASS

Food Access Metrics

The proposed ABM considers a set of agents $\mathcal{A} = \{1, ..., A\}$, where each agent corresponds to a household. Every agent makes n trips to a food source during the month. In this study, two types of food sources are considered: supermarkets (S) and convenience stores (C). At each trip $i \in \{1, ..., n\}$, agent $a \in \mathcal{A}$ selects a food source $s_{a,i} \in \mathcal{S} = \{S, C\}$, where the probability of selecting a supermarket, denoted by $P_a(S)$, is defined by Equation (1).

$$P_a(S) = \left(\frac{\beta_a}{B} \times w_\beta\right) + (\nu_a \times w_\nu) + \epsilon, \tag{1}$$

where w_β, β_a, B, ν_a, w_ν, and ϵ are the weight associated with the income, agents budget, the population's maximum budget, the number of vehicles available to the agent, weight associated with vehicle access, and a constant to ensure that agents have access to a food source, respectively.

The Monthly Food Access Index (MFAI) of agent $a \in \mathcal{A}$ is then defined as

$$\text{MFAI}(a) = \frac{1}{\gamma_a} \times \frac{1}{n} \sum_{i=1}^{n} \sigma(s_{a,i}), \tag{2}$$

where γ_a is an agent-specific burden factor and $\sigma(s)$ is the nutrition score of food source $s \in \mathcal{S}$. The burden factor $\gamma_a > 1$ if agent a has no vehicle ($\nu_a = 0$) and $\gamma_a = 1$ otherwise. In addition, supermarkets have a higher nutrition score than convenience stores, i.e., $\sigma(S) > \sigma(C)$, reflecting supermarkets' larger selection and higher quality of food items compared to convenience stores.

Case Study

Franklin County in Columbus, Ohio, was chosen as the initial study area due to its diverse socioeconomic composition, providing a representative landscape for analyzing food security challenges.

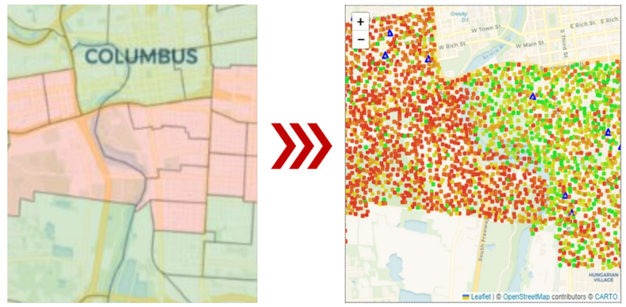

Figure 3. Test Case: Columbus, Ohio

Preliminary findings reveal an average MFAI score of 84.22 across households, suggesting relatively high access levels when both supermarkets and convenience stores are available. This baseline score establishes current food access conditions in the area, with results indicating a stable pattern over time. These initial experiments demonstrate the model's capacity to evaluate existing food access and provide a basis for assessing potential policy changes.

Sensitivity

A sensitivity analysis was conducted to assess the impact of supermarket availability on food access. When the supermarket option was removed, the average MFAI score dropped sharply to 49.26, underscoring the vital role supermarkets play in providing nutritious food choices. This significant decline illustrates the reduced food access quality that occurs when communities must rely solely on convenience stores. The analysis highlights the importance of supermarkets in mitigating food deserts and improving overall food accessibility, especially in underserved neighborhoods.

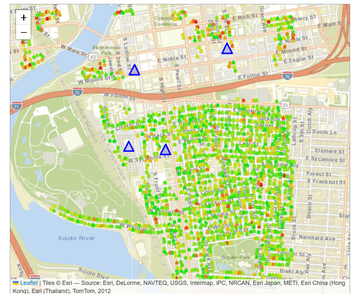

Figure 4. Four Stores

*average MFAI score of 84.22

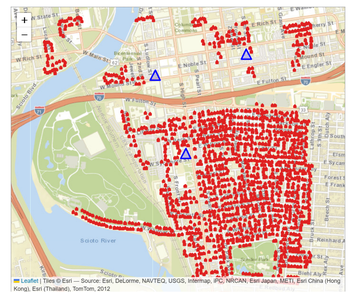

Figure 5. Three Stores

*average MFAI score of 49.26

Future Work

This study is part of an ongoing research collaboration between academics and practitioners. Future work is aimed at refining and expanding the model's capabilities. While the current version provides a framework for assessing food accessibility, limitations exist. Currently, the MFAI does not account for the distance between households and stores, an important factor in real-world food accessibility. Incorporating distance will improve the model's accuracy and reflect the travel burdens faced by households in accessing food. Future iterations will also integrate additional factors, such as weather conditions and transportation infrastructure, to capture dynamic influences on food access. Long-term plans for FASS include expanding the model to more geographic regions and incorporating more complex household dynamics. By addressing these areas, FASS will serve as an adaptable tool for guiding effective policies to reduce food insecurity.

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rosemarie.santa@gatech.edu